TECHNICAL SERVICE CENTER
Denver, Colorado

Predicted Effects of Sediment Discharge from the Elwha Water Treatment Plant

Prepared by
US Department of the Interior
Bureau of Reclamation
Water Resources Services Division
Sedimentation and River Hydraulics Group

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Summary and Conclusions

The Elwha River Ecosystem and Fisheries Restoration Project (Project) will remove the Elwha and Glines Canyon Dams to restore the Elwha River for native resident and anadromous fish species that have been cut off since Elwha Dam was constructed in the mid-1910s. The approach proposed for removal of the dams will permit a gradual lowering of the reservoir water surfaces. This approach will use the river's energy to erode a portion of the sediments, which have accumulated in both reservoirs since the dams were constructed, and transport this material downstream to the lower reaches of the river and the Strait of Juan de Fuca. The sediment erosion will result in periodic, high suspended sediment concentrations in the river during the dam removal and sediment erosion phase. The high suspended sediment concentrations will adversely affect water quality for several downstream water users. The Elwha Water Treatment Plant (EWTP) will be constructed about 3 river miles upstream from the mouth of the Elwha River to treat this water and mitigate these impacts for several of the high-demand water users during the period of dam removal and sediment release from the reservoirs. The EWTP will treat river water to remove suspended sediments from the river water and return the residual solids to the river.

The sediments eroded from the reservoirs during dam removal will have far more impact on water quality and the river channel than the residual solids discharged by the EWTP. The solids discharge outfall location proposed is at a riffle where sediment transport capacity will be highest and there is little or no risk of suspended sediments depositing. The residual solids will consist of the flocculated sediments, which will be small light particles that are easily disrupted. When these residual solids are discharged to the river, they will be transported as suspended wash load.

Calculations of sediment transport capacity indicate that the fine-sized sediment (less than 0.062 mm) can be transported in suspension downstream to the mouth during dam removal, even during periods of maximum loading. Because the sediment transport capacity of the river would still exceed the upstream supply of fine sediment (even during dam removal), the EWTP solids discharge is expected to be quickly suspended and mixed with the suspended sediment in the river, making it difficult to detect any impact downstream of the outfall location. These particles are not likely to settle in the river under most conditions because their structure will be disrupted as they are pumped from the EWTP to the river, and the turbulent river conditions will prevent the particles from depositing in the river. There could be some fine sediment deposition in slow velocity eddies along the river banks and on the floodplain during flood flows. Because of these characteristics and the fact that there are a limited number of slow-velocity areas along the Elwha River, except during periods of flooding, the vast majority of the fine sediments, including the residual solids, will be transported to the Strait of Juan de Fuca.

The discharge of residual solids from the EWTP is predicted to increase suspended sediment concentrations in the river by about 6 percent and occasionally by as much as 13 percent. Research in rivers with high sediment loads indicates that this increase in suspended sediment concentration will actually increase the sediment transport capacity of the Elwha River during brief periods when the sediment concentrations are already high (tens of thousands of mg/l). This increase in sediment transport capacity, the location of the solids discharge outfall in a high

transport area, and the fact that the sediment transport capacity exceeds the supply for the sizes of sediment that will be released from the EWTP, indicate that the impacts from solids discharge from the EWTP will be minimal and additional modeling or study to address this issue is not warranted.

Numerical hydraulic and sediment transport modeling has been previously accomplished for the project to assess the volume, sizes, and timing of sediment that will be eroded from the two reservoirs under the dam removal plan and four possible hydrologic scenarios. In addition, the numerical modeling provides general sediment transport predictions and identifies areas that may be subject to temporary deposition and channel changes during and immediately following dam removal. For the EWTP, the results from these modeling efforts along with historical aerial photograph analysis were used to assess the impacts from the sediment discharged from the EWTP into the Elwha River and to provide a recommendation for the location for the solids discharge outfall. Detailed, physically-based numerical modeling of sediment transport and mixing in the high velocities and turbulence of the riffle would only be possible with a three-dimensional hydraulics and sediment transport model. Presently, such models only exist in a research status and are not yet ready for predictive use for this type of project. In addition, the data required to calibrate such a model do not exist. Even if such detailed modeling were conducted, the results would not change the conclusions of this report.

The proposed location of the EWTP solids discharge outlet is recommended for the following reasons:
1. the outfall is in a riffle with relatively high river velocities and turbulence that can easily transport and mix the solids discharged from the EWTP,
2. the outfall is near the EWTP, and
3. the river channel at the outfall has been stable in position since at least 1939, because the floodplain is locally constricted.

The river channel at this location is not expected to experience lateral migration during or after dam removal. If desired, a contingency plan could be developed to locally protect the terrace banks if future monitoring indicated that river channel was laterally migrating away from the solids discharge outfall.

Dam Removal and Reservoir Sediment Erosion

The lower Elwha River will be subjected to high sediment loads from the two upstream reservoirs during dam removal and natural sediment loads from the upstream watershed after dam removal. In 1994, approximately 17.7 million yd^3 of sediment were stored in the reservoirs behind the two dams (Gilbert and Link, 1995). The size distributions of reservoir sediments in Lake Mills and Lake Aldwell are shown in Figures 1 and 2. The sediment particle diameters that define the divisions between clay, silt, sand, gravel, and cobble are listed in Table 1.
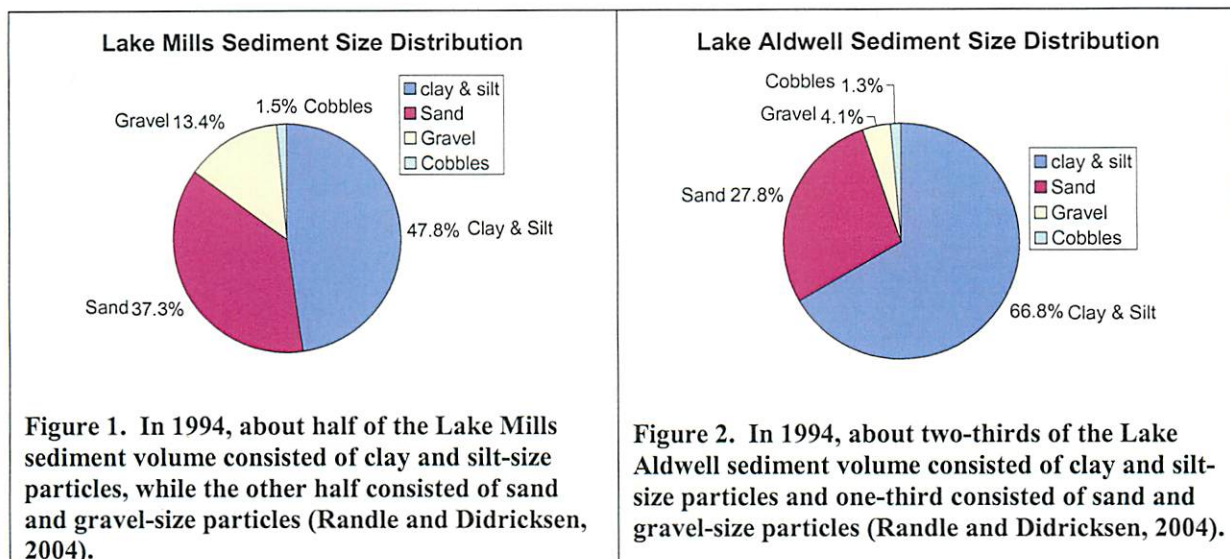
Lake Mills Sediment Size Distribution

Gravel 13.4%

1.5% Cobbles

47.8% Clay & Silt

Sand 37.3%

Legend: clay & silt, Sand, Gravel, Cobbles

Figure 1. In 1994, about half of the Lake Mills sediment volume consisted of clay and silt-size particles, while the other half consisted of sand and gravel-size particles (Randle and Didricksen, 2004).

Lake Aldwell Sediment Size Distribution

Cobbles 1.3%

Gravel 4.1%

Sand 27.8%

66.8% Clay & Silt

Legend: clay & silt, Sand, Gravel, Cobbles

Figure 2. In 1994, about two-thirds of the Lake Aldwell sediment volume consisted of clay and silt-size particles and one-third consisted of sand and gravel-size particles (Randle and Didricksen, 2004).

Table 1. Sediment size class and particle diameter range	
Sediment Size Class	Particle Diameter Range (mm)
Clay	1/4096 to 1/256
Silt	1/256 to 1/16
Sand	1/16 to 2
Gravel	2 to 64
Cobble	64 to 250

Of the 17.7 million yd^3 of reservoir sediment, between 7.2 million and 7.9 million yd^3 of sediment are expected to erode from the upstream reservoirs (see Appendix A). The range in the predicted sediment erosion volumes varies with the potential range of future hydrology modeled (Randle and others 1996). Of the sediment volume eroded from the reservoirs, 1.9 million to 2.6 million yd^3 is expected to be coarse grained material (sand, gravel, and cobble-sized) and 4.6 million to 5.5 million yd^3 is expected to be fine grained material (clay and silt-sized). The remaining reservoir sediment is expected to stabilize and become covered with vegetation and remain in the reservoir over the long term.

Elwha Water Treatment Plant

The EWTP will remove suspended solids from water diverted from the river and provide the treated water for several users who are currently using water directly from the river without treatment. The facility will operate during the period of dam removal and sediment release from the reservoirs, which begins with the dam removal and is expected for last for three to five years following dam removal. The EWTP will use a coagulation and sedimentation treatment process to remove suspended solids from the river water. The residual solids generated by the EWTP will be discharged from the treatment process to the river (see Figure 3). The residual solids will

consist of the flocculated sediments[1], which will be small light particles that are easily disrupted when exposed to the turbulence of river flow (Ochiltree, 2003).

Figure 3. Aerial photograph of the Elwha River from 2000. The red circle in the photograph shows the proposed location for the solids discharge outfall from the EWTP. The blue line shows the centerline of the active river channel.

During the dam removal process, peak suspended sediment concentrations in the Elwha River could occasionally reach up to 40,000 mg/l (total suspended solids). Sediment, suspended in the river water, is expected to enter the EWTP at about the same concentrations as that in the river channel. This suspended sediment is expected to consist of clay, silt, and sand-sized sediments. A recent physical model of the new diversion facility showed that it is effective at avoiding the diversion of coarse bed-load sediments, including sand suspended near the river bed (Mefford, 2004). The EWTP is designed to treat this water to a turbidity of approximately 20 nephelometric turbidity units (NTU). The treated water demand from the EWTP will range from 13.8 to 51.9 million gallons per day (mgd) depending on the time of year and the river water quality (see Table 2). This range in water demand is equivalent to an average flow rate range of 21 to 80 ft^3/s. Discharges of residual solids from the EWTP will be continuous while the plant is operating. Solids discharge rates will range from approximately 2 to 18 ft^3/s, and solids concentrations will range up to 20 percent (approximately 200,000 mg/L). The solids will be discharged from two pipes located at the outside of a bend in the river downstream of the EWTP (see Figure 3).

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[1] Very fine, fluffy mass formed by the aggregation of fine suspended sediments.

Table 2. Water Demand Summary

	Normal (mgd)	Maximum (mgd)
Average	20.6	36.8
Minimum	13.8	30.0
Maximum	35.6	51.8
Frequency	*~99%*	*~1%*

The water quality impact of discharging solids from the EWTP into the Elwha River will be a function of the solids discharge rate and the rate of river flow and suspended sediment concentration. Solids discharge rates from the EWTP will vary with the sediment concentration in the river and with the demand for treated water. Table 3 outlines the incremental impacts to the river sediment concentration for three EWTP operating conditions for both low and average river flows of 500 and 1,500 ft^3/s. The evaluation presented in Table 3 shows that the increase in suspended sediment concentrations in the river will be less than 6 percent under the majority of operating conditions (99 percent of the time). Under the worst case conditions, which are likely to occur less than 1 percent of the time, the sediment concentrations may be increased by as much as 13 percent.

Table 3. Estimated Impacts on River Sediment Concentration (Ochiltree, 2003).

Parameter	Units	Parameter Values					
Treatment Plant Operating Conditions		1		2		3	
Frequency of occurrence		*~79%*		*~20%*		*~1%*	
Demand for treated water	mgd (ft^3/s)	Average demand 20.6 (31.9)		Average demand 20.6 (31.9)		Maximum demand 51.8 (64.4)	
EWTP inflow concentration	mg/l	500		10,000		40,000	
EWTP solids discharge concentration	mg/l	60,000		200,000		200,000	
EWTP solids discharge rate	Gpm (ft^3/s)	120 (0.268)		762 (1.7)		7,623 (17)	
River Conditions		Low	Average	Low	Average	Low	Average
Flow rate upstream from EWTP solids discharge	ft^3/s	500	1500	500	1500	500	1500
Sediment concentration upstream from EWTP solids discharge	mg/l	500		10,000		40,000	
Sediment concentration downstream from EWTP solids discharge	mg/l	532	511	10,642	10,214	45,240	41,780
Increase in sediment concentration		6%	2%	6%	2%	13%	5%

Elwha River Sediment Transport

The gravel and cobble-sized sediments that are eroded from the reservoirs are expected to be transported along the bottom of the river channel as bed load (Figure 4). The sand-sized sediment may also be transported as bed load, but a large portion of the sand load would also be transported by being suspended in the river flow (suspended sediment load). Silt and clay-sized particles have diameters that are finer than 0.062 mm and will be easily transported as suspended sediment load (also referred to as wash load) and are not expected to deposit on the bottom of the river channel. Clay and silt size particles are expected to travel at nearly the speed of the river flow, while sand, gravel, and cobbles will be transported at much slower rates.
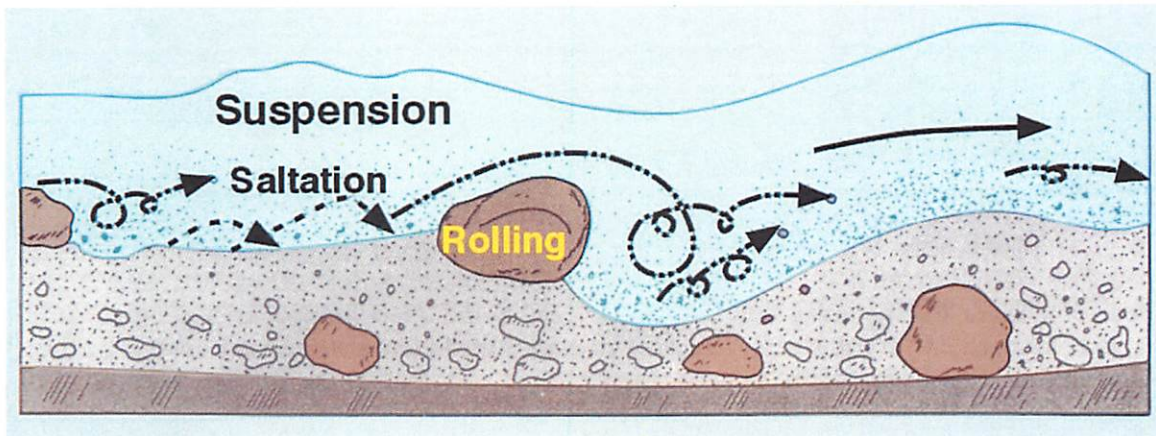
Figure 4. Finer sediments are transported in suspension while coarser sediments are transported as bed load where particles move along the riverbed by rolling or saltation.

Clay and silt-sized sediments are expected to affect water quality because they will be suspended in the water column. Concentrations of clay and silt, during dam removal, are expected to be highly variable and peak concentrations in the river could occasionally reach 40,000 mg/l as shown in Figure 5.
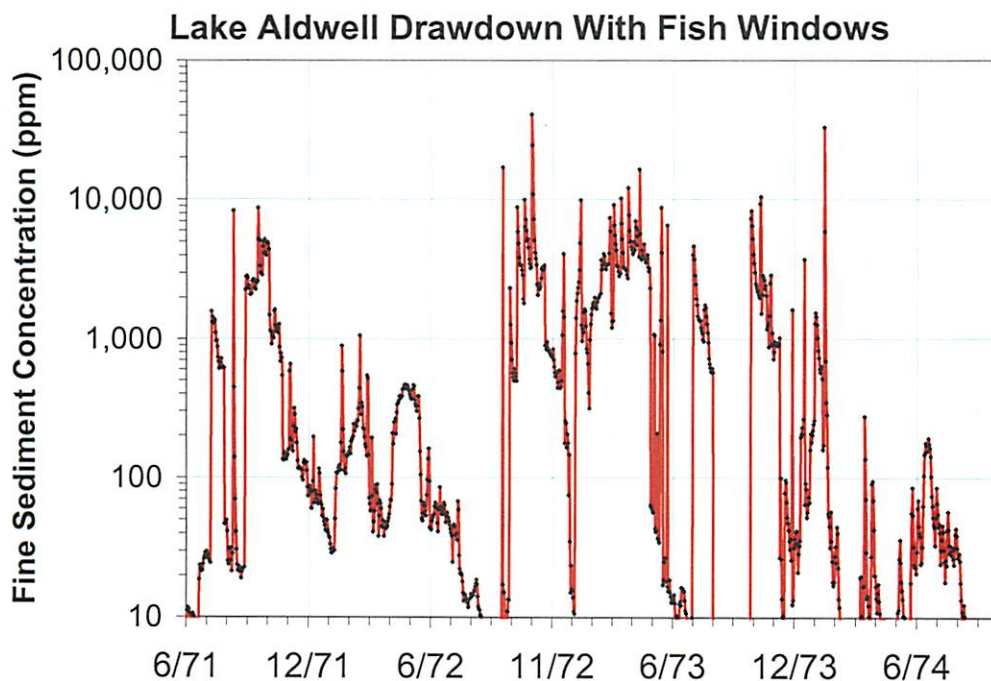

Figure 5. There is a large range in the predicted variation in suspended sediment concentration during the concurrent removal of both dams. These predictions rely on the historic river flows for the period 1971 to 1974 (Randle and others 1996). The model results presented are in ppm rather than mg/L. At very low concentrations, ppm computations are nearly equal to mg/L. For higher concentrations the difference becomes greater, but for concentrations less than 145,000 ppm, the difference is still less than 10 percent (Julien, 1995). Therefore, for maximum concentration values discussed in this report at one digit of precision the results presented in Figure 5 can be referred to as ppm or mg/L.

The Elwha River is too steep, and the flow velocities are too fast, for significant quantities of fine sediment particles (including residual solids) to deposit and accumulate on the riverbed. A one-dimensional hydraulic model (HEC-RAS V3.1) was developed for the Elwha River to predict the flood stage associated with various river flows. Topographic data for this model were based on a 2000 LIDAR survey of the floodplain and a 2000 bathymetric survey of the river channel. The model predictions of water surface elevation were calibrated to high water marks.

The minimum, average, and maximum velocities of the Elwha River along the downstream most three river miles are presented in Table 4 for a range of river flows (based on the one-dimensional HEC-RAS model) and compared with the critical velocity[2] required to maintain the transport of the fine sediments in suspension. Figure 6 shows the average channel velocities along the lower Elwha River for flows of 500, 1,500, and 14,470 ft^3/s. A table of these velocities, for each river cross section in the model, is presented in Appendix B. Even the minimum river velocity, during a very low flow of 300 ft^3/s, is more than 5 times faster than the critical velocity to maintain sediment transport of the fine sediment particles. The maximum river velocity during a 2-year flood (14,470 ft^3/s) is more than 50 times faster than the critical velocity to maintain sediment transport. If fine sediment particles did begin to settle along the riverbed between the larger cobbles, the lift force generated by the river water flowing over the cobbles normally would be great enough to overcome the velocity of any water flowing into the riverbed and alluvial aquifer. Therefore, the fine sediment particles would be re-suspended and prevented from accumulating on the riverbed.

Table 4. Range of average river channel velocities for a range of flow conditions.				
River Flow (ft^3/s)	River Channel Velocity (ft/s)			Critical Velocity[2] (ft/s) for a sediment particle diameter of 0.062 mm
	Minimum	Average	Maximum	
300	0.1	1.8	5.6	
1,630	0.5	3.2	7.3	0.017
5,000	1.0	4.6	9.7	
14,470	1.1	6.3	11.1	

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[2] The critical velocity (V_{cr}) required to initiate or maintain sediment transport can be calculated as a function of the sediment particle fall velocity (ω). The equation for critical velocity under turbulent flow is: $Vcr = 2.05\ \omega$ (Yang, 1973).
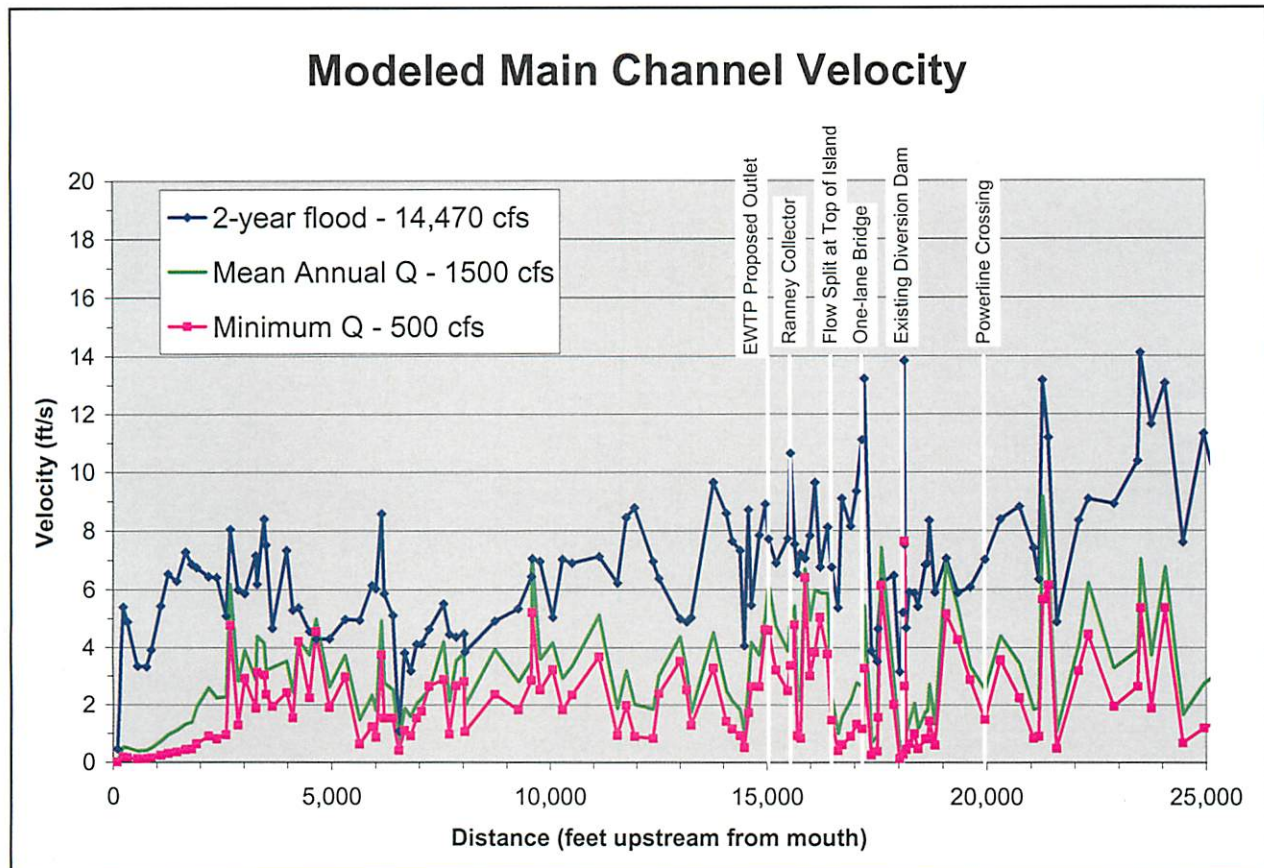
Figure 6. Average flow velocities along the lower Elwha River during flows of 500, 1,500 and, 14,470 ft³/s.

The fine sediment discharged from the EWTP would be carried as wash load and is not expected to exceed the transport capacity of the Elwha River. In fact, when the concentrations of suspended sediment in the river are greater than about 10,000 mg/l, they increase the viscosity and density of the sediment-fluid mixture, which in turn decreases the sediment particle fall velocity and increases the sediment transport capacity for both suspended sediment and bed load (Yang, 1996).

Using output from the one-dimensional hydraulic model created for the Project, sediment transport capacity computations were performed using the Yang (1973) equation to get a general indication of the sediment transport capacity for fine sediments up to 0.062 mm. In addition, the influence of high suspended sediment concentrations on the transport capacity was also evaluated using an equation by Yang (1996). Computations show that the sediment transport capacity for fine sediment, even at low flows, typically exceeds 100,000 mg/l, except for deep pools and near the river mouth. The deep river pools would most likely fill with sand and gravel rather than fine silt and clay. Further, at a suspended sediment concentration of 40,000 mg/l, the sediment transport capacity for fine sediment would be expected to increase by 40 to 50 percent at the 2-year flood.

Sediment Deposition and River Planform Adjustment

The width, depth, and planform of a river channel are a function of the upstream supply of water and sediment, the slope of the river valley, and the constraints imposed by bed rock, vegetation, and man-made structures. The actual sediment load of a river is either limited by the upstream sediment supply or the hydraulic capacity of the river to move sediment. If the hydraulic capacity to move sediment is greater than the upstream supply, then sediment will be eroded from the bed and banks until the channel slope and sediment transport capacity have been sufficiently reduced (through a more meandering planform) or until the bed becomes armored with large particles that cannot be transported by the river flow. If the sediment supply is greater than the hydraulic capacity to move sediment, then sediment will deposit along the river channel and the river channel will evolve to a straighter and more braided planform with a higher sediment transport capacity.

The upstream supply of coarse sediment to the lower Elwha River was cutoff by the final construction of Elwha Dam in 1913. As a result the river channel has eroded and evolved to a more meandering planform and the riverbed has become armored with cobbles and boulders (Gilbert and Link, 1996). The only remaining sediment sources to the lower Elwha River are from the lateral erosion of floodplain and terrace banks along the river. Presently, the downstream most three miles of the Elwha River flow through a meandering cobble and boulder-bed river channel with pools and riffles. The average longitudinal slope of these three miles is 0.0034, which represents a fairly steep river channel (see Figure 7).

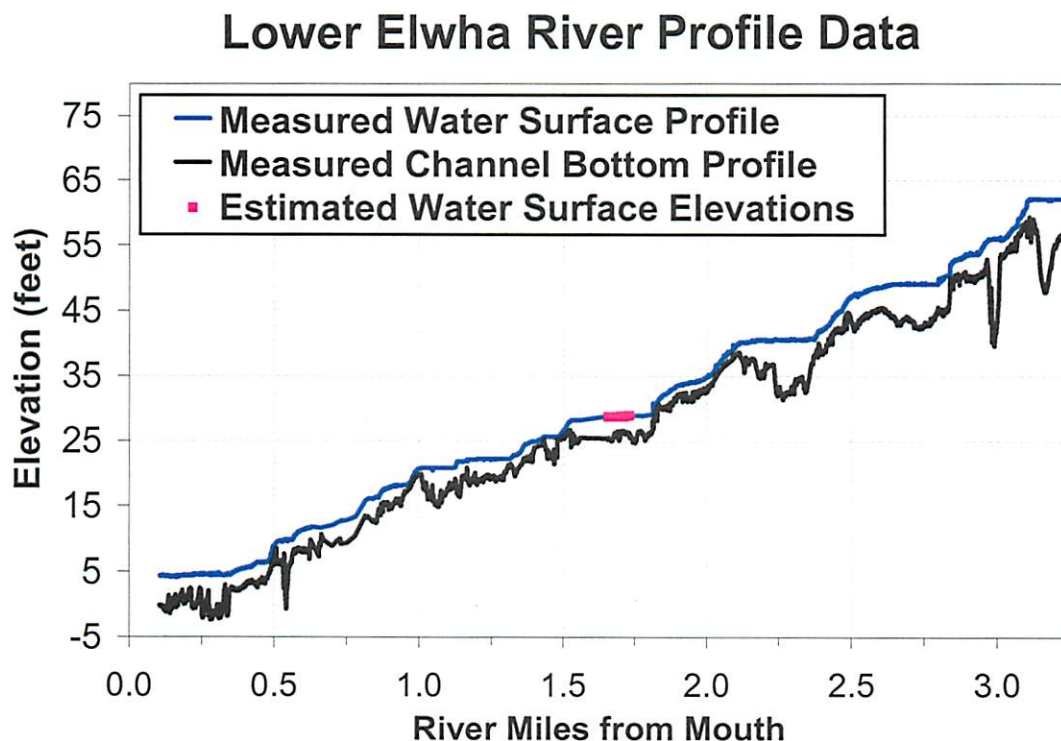## Lower Elwha River Profile Data

Figure 7. The longitudinal profile of the lower Elwha River is relatively steep with an average slope of 0.0034. This profile was produced from the 2001 river channel survey data at an average discharge of 990 ft3/s.

With the planned removal of Glines Canyon and Elwha Dams over a two to three-year period, there will be a large increase in the sediment supply to the downstream river channel from the erosion of reservoir sediments and from the sediments naturally supplied by the upstream watershed. Sediment is expected to erode from the upstream reservoirs primarily during periods of dam removal and reservoir drawdown when river flows would be low. Therefore, as sand and gravel-sized sediments are eroded from the reservoirs during low-flow periods, these sediments will progressively deposit in river pools as they are transported downstream until the pools become full of sediment and the water surface profile becomes more uniform and steep. Flood flows that occur between increments of dam removal would progressively flush at least a portion of the sediment deposited in the river pools.

The riffles in the present river channel are too steep, and the flow velocities are too high, for sand and fine gravel to deposit in these high-energy environments. The riffles hydraulically control the upstream water surface elevations of the river. Therefore, the water surface elevations of the river cannot significantly increase without sediment aggrading the riffles. Coarse sediment depositing in a river pool could possibly aggrade the toe of the next upstream riffle and the deposition pattern could progress upstream to the top of the riffle. If coarse sediment were to aggrade the river channel, then the channel would tend to adjust to a straighter and more braided planform (see Figure 8). This straighter alignment depicted in Figure 8 would increase the average slope from 0.0034 to 0.0044, which is an increase of 29 percent. The steeper slope would also increase the sediment transport capacity and further reduce the potential for aggradation. If aggradation were to continue (especially on the riffles) the river water surface elevations would increase, which would force more water into side channels and create a braided planform, and the river would begin migrating across the floodplain at an accelerated rate. As the sediment loads return to more natural levels following dam removal, the river is expected to return to a more meandering planform.
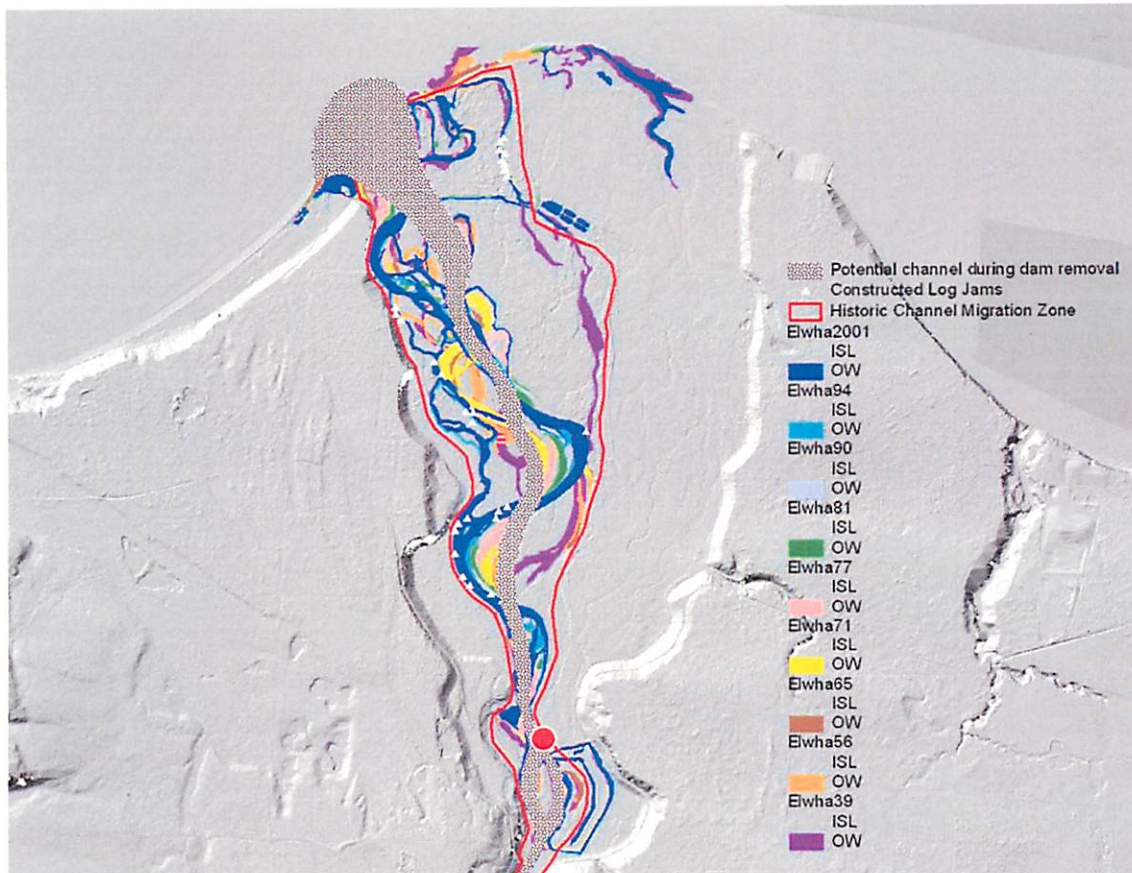
Figure 8. The estimated future planform of the Elwha River would be a relatively wide, straight, and braided river channel with some flow entering the existing and historic river channels. A new delta is expected to deposit at the river mouth. The location of the EWTP outfall is identified by the red circle. Historical channels shown in the figure represent low-flow channels from various historical aerial photographs (i.e., 77 represents channel position in 1977). The locations of log jams, constructed by the Tribe, are shown in the figure as white triangles.

Channel migration across the floodplain, caused by an aggrading riverbed, would eventually raise the elevation of the entire floodplain. If all of the coarse sediment that is expected to erode from the reservoirs (1.9 million to 2.6 million yd^3 of sand, gravel, and cobbles) were to deposit across the entire floodplain and river channel, downstream from Elwha Dam (rather than reaching the Strait of Juan de Fuca), the average deposition thickness would range between 1.7 and 2.4 feet, which would increase river water surface elevations by the same amount (Randle, 2002, see Appendix A). However, a large portion of the coarse reservoir sediments are expected to be transported all the way to the river mouth at the Strait of Juan de Fuca, so the actual amounts of aggradation within the lower 3 miles should be much less. Therefore the actual amounts of water surface increase would also be less. Over the long term, the river is expected to become more meandering than braided once the processes are driven by natural sediment loads.

Solids Discharge Outfall Location

A location for the solids discharge outfall was recommended by Reclamation based on the criteria that it was within a reasonably close distance to the EWTP, it was in a location where the

river channel would not migrate away from the solids discharge outfall, and it was in a section of river that had relatively high transport capacity. In the vicinity of the EWTP, there are two flow paths in the Elwha River separated by a vegetated island. The amount of flow conveyed down the right channel path (looking downstream) is partially controlled by a manmade structure at its entrance. Although the Elwha River channel has historically migrated across the floodplain at most locations, the river channel at the downstream end of the island has not moved since 1939, is bound by terraces on either side of the channel, and conveys all of the main channel flow at any given time which helps increase the sediment transport capacity (Figure 9). Additionally, at this point a riffle presently exists where the sediment transport capacity of the river is higher than in pool sections that may be subject to at least temporary filling (aggradation) from high sediment loads during dam removal. For these reasons, the outfall is proposed at the downstream end of the island as shown in Figure 9. This trend of a locally stable position of the river, at the proposed discharge outfall, is expected to continue during and after dam removal (see Figure 8) because the floodplain is locally constricted at this location. If desired, a contingency plan could be developed to locally protect the terrace banks if monitoring indicates the river channel is laterally migrating away from the solids discharge outfall location.
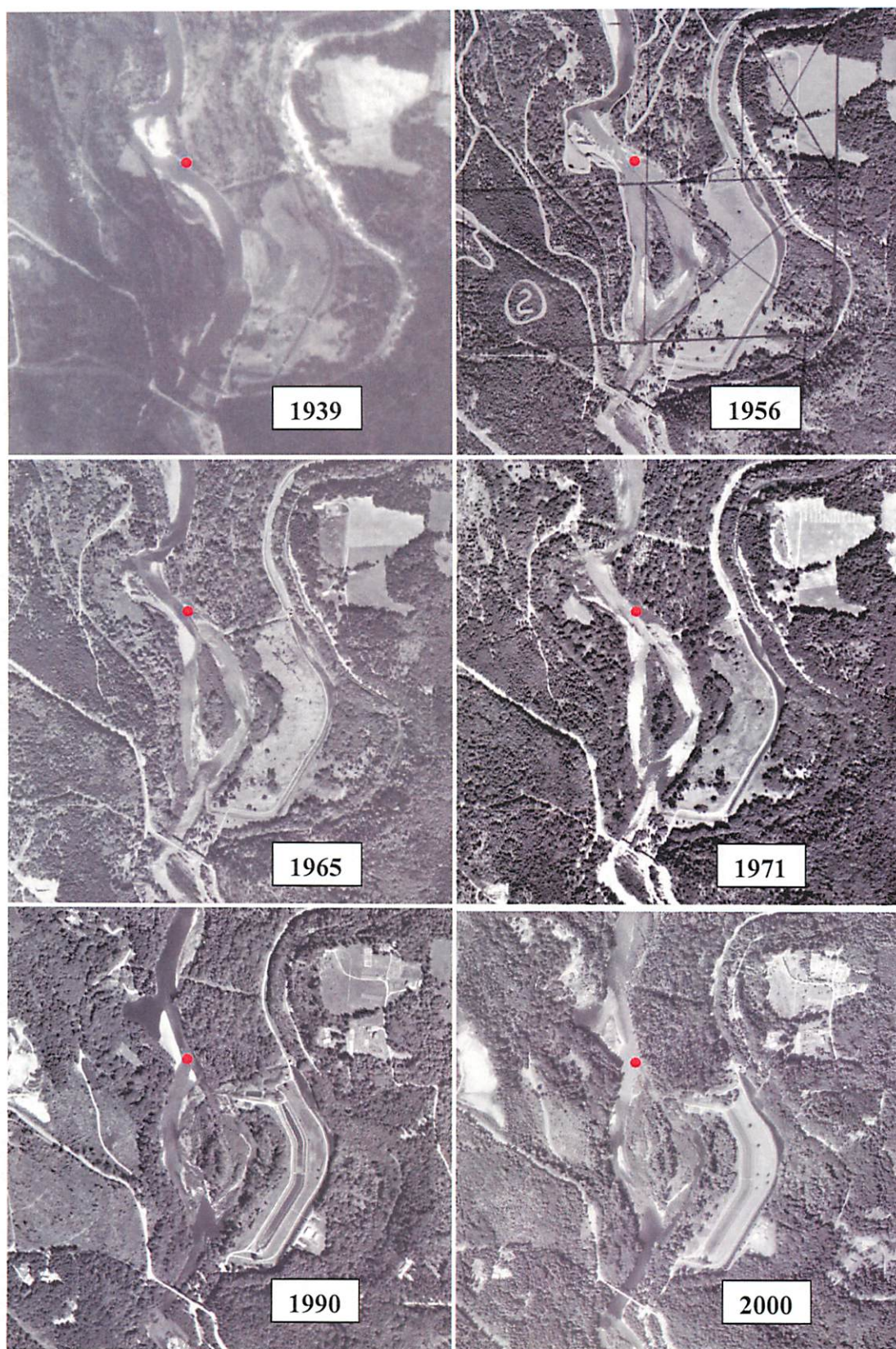
Figure 9. Series of historical aerial photographs at proposed solids discharge outfall location (shown as red circle) for EWTP.

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Appendix A: Summary of Sediment Modeling Results

D-8540
RES-3.10

December 4, 2002

MEMORANDUM

TO: Olympic Elwha Project Team Leader, Elwha River Restoration Project, Olympic National Park,
            National Park Service, U.S. Department of the Interior, 826 East Front Street, Suite A,
            Port Angeles, WA 98362
              Attention: Dr. Brian Winter

FROM: Timothy J. Randle, Hydraulic Engineer
            Sedimentation and River Hydraulics Group
            Technical Service Center

SUBJECT: Application of the Report Entitled: "Sediment Analysis and Modeling of the River Erosion
            Alternative", Elwha Technical Series PN-95-9, Randle, Young, Melena, and Ouellette,
            U.S. Bureau of Reclamation, October 1996

The purpose of this memorandum is to provide guidance on how to apply results from the subject report to a new
hydraulic model that uses 2001 survey data of the Elwha River and flood plains in the 5-mile reach between
Elwha Dam and the mouth.

Overview of Sediment Modeling

The October 1996 sediment modeling and analysis report was prepared in support of the draft and final
environmental impact statement for the "Elwha River Ecosystem Restoration Implementation" (Olympic National
Park, April and November, 1996). The modeling and analysis report documented predictions of how much reservoir
sediment would be eroded from Lake Mills and Lake Aldwell during concurrent removal of Glines Canyon and Elwha
Dams. The report also provides predictions on how this eroded sediment would be transported and deposited along
the downstream river channel and how sediment deposition (aggradation) would increase water surface elevations
during a possible 100-year flood over a short- and long-term timeframe.

Reservoir Erosion Model Results

U.S. Bureau of Reclamation (Reclamation), in cooperation with the National Park Service, created a new reservoir-
sediment-erosion model for the Elwha River Restoration Project. This model predicted that between 15 and
32 percent of the 8.50 million yd^3 of coarse sediment (sand, gravel, and cobbles) would be eroded from the two
reservoirs over a 3-year period during and immediately following dam removal. The model also predicted that
between 53 and 61 percent of the 9.21 million yd^3 of fine sediment (clay and silt) would be eroded from the two
reservoirs during the same 3-year period. The report concluded that remaining reservoir sediment would become
stable and remain in the two reservoirs over the long-term. Recent updates and refinements to the reservoir erosion
model in 2002 have resulted in slight revisions to the predicted volume of sediment being delivered to the
downstream river channel. New model results predict that between 23 and 31 percent of the coarse sediment and
between 50 and 60 percent of the fine sediment would be eroded from the reservoirs over a 13-year period during

and immediately following dam removal (see table 1). Vegetation is expected to colonize and stabilize the remaining reservoir sediment within 3 to 5 years following dam removal.

Table 1. Reservoir Sediment Erosion Summary Using Four Hydrologic Periods							
	Predicted Reservoir Sediment Erosion						
1994 Reservoir Sediment Volumes (yd^3)		1950 to 1963	1968 to 1981	1971 to 1984	1989 to 2002	Minimum	Maximum
Total Lake Mills Sediment	13,830,000	35%	39%	37%	34%	34%	39%
½ Sand & Gravel	7,210,000	14%	20%	16%	23%	14%	23%
½ Silt & Clay	6,620,000	58%	60%	60%	46%	46%	60%
Total Lake Aldwell Sediment	3,880,000	63%	63%	63%	64%	63%	64%
1/3 Sand & Gravel	1,290,000	71%	71%	72%	73%	71%	73%
2/3 Silt & Clay	2,590,000	59%	59%	59%	60%	59%	60%
Total Reservoir Sediment	17,710,000	41%	45%	43%	41%	41%	45%
Sand & Gravel	8,500,000	23%	28%	25%	31%	23%	31%
Silt & Clay	9,210,000	58%	60%	60%	50%	50%	60%
	Predicted Reservoir Sediment Erosion Volumes (yd^3)						
1994 Reservoir Sediment Volumes (yd^3)		1950 to 1963	1968 to 1981	1971 to 1984	1989 to 2002	Minimum	Maximum
Total Lake Mills Sediment	13,830,000	4,830,000	5,440,000	5,120,000	4,710,000	4,710,000	5,440,000
½ Sand & Gravel	7,210,000	1,010,000	1,460,000	1,160,000	1,660,000	1,010,000	1,660,000
½ Silt & Clay	6,620,000	3,820,000	3,980,000	3,960,000	3,050,000	3,050,000	3,980,000
Total Lake Aldwell Sediment	3,880,000	2,440,000	2,460,000	2,460,000	2,480,000	2,440,000	2,480,000
1/3 Sand & Gravel	1,290,000	910,000	920,000	930,000	940,000	910,000	940,000
2/3 Silt & Clay	2,590,000	1,530,000	1,540,000	1,530,000	1,540,000	1,530,000	1,540,000
Total Reservoir Sediment	17,710,000	7,270,000	7,900,000	7,580,000	7,190,000	7,190,000	7,900,000
Sand & Gravel	8,500,000	1,920,000	2,380,000	2,090,000	2,600,000	1,920,000	2,600,000
Silt & Clay	9,210,000	5,350,000	5,520,000	5,490,000	4,590,000	4,590,000	5,520,000

The reservoir sediment erosion model results are based on the simulation of four separate hydrologic periods:

- 1950 – 1963 represents a dam removal period that begins with one year of relatively high annual peak discharge, followed a year of relatively low, and then a year of moderate peak discharge.
- 1968 – 1981 represents a dam removal period that begins with the lowest peak discharges for any three consecutive water years of record.
- 1971 – 1984 represents a dam removal period that begins with progressively higher annual peak discharges in each of the first three years.
- 1989 – 2002 represents a dam removal period that begins with the highest peak discharges for any three consecutive water years of record.

The reservoir sediment erosion model predicted that the river would erode a channel (of a certain width) completely through the sediment of each reservoir. To be conservative, the minimum width of the erosion channel through each reservoir was computed using an empirically based equation developed for the widest reach of the Elwha River. The width of this erosion channel would be between 630 and 1,500 feet wide with the greater width being at the higher elevations. A relatively small percentage of the coarse sediment would be eroded (23 to 31 percent) because the coarse sediment is presently in the delta at the upstream end of the reservoir. This sediment would be eroded and

redeposited across the reservoir during progressive increments of dam removal and much of it remaining along the margins of the reservoir.

HEC-6 Model Application

The volume of fine sediment predicted to erode from the reservoirs was assumed to be transported in suspension (without deposition) all the way to the Strait of Juan de Fuca. The Army Corps of Engineers, HEC-6 sediment transport model was applied to predict how much of the eroded coarse sediment would deposit and aggrade the riverbed downstream of Elwha Dam over both the short- and long-term (3 and 53 years following the start of dam removal). All of the coarse sediment eroded from Lake Mills was assumed to be transported to Lake Aldwell without deposition in the middle reach between the two reservoirs. The HEC-6 model used a total of 29 cross sections to represent the 5-mile reach of the Elwha River between the mouth and Elwha Dam. Of these 29 cross sections, 20 sections were surveyed in 1994, 8 sections were duplicated from a portion of the surveyed sections, and a wide, shallow, rectangular cross section was added to represent the river mouth. These 29 cross sections were the best available data at the time and tended to represent the average slope of the riverbed. However, they did not fully define localized changes in slope caused by the series of pools and riffles that form the lower Elwha River channel.

The series of river pools between Elwha Dam and the river mouth could contain 500,000 yd^3 of sediment during periods of low flow.

HEC-6 Model Results

Between river miles 0 (Elwha River mouth) and 4.04 (downstream end of bedrock canyon), the HEC-6 model predicted that the riverbed would aggrade between 0 and 10 feet (with an average of 2.7 feet) over the short term (3 years) (see table 2 and figure 1). The greatest amount of aggradation predicted was along reaches with flatter slopes where cross sections were duplicated. The model also predicted that this short-term aggradation from erosion of reservoir sediments would increase the 100-year flood stage by an average of 0.7 feet. Over the long-term (53 years), the model predicted that the riverbed would continue to aggrade from the restoration of the natural upstream sediment supply, and that the average aggradation would reach 4.6 feet. This long-term aggradation was predicted to increase the 100-year flood stage by an average of 2.5 feet.

In reality, the erosion and release of coarse sediment from the reservoirs is expected to successively aggrade river pools in a downstream progression over the short term. The water surface profile would only significantly increase if there were significant aggradation on the riffles, which have steeper slope, higher river velocity, and higher sediment-transport capacity than river pools. If coarse sediment did aggrade the riffles, then river flows would begin to enter and widen secondary river channels. Thus, the river channel would tend to migrate laterally by occupying and eroding the banks and vegetation of old river channels. This means that the river channel would move laterally if the amount of aggradation became too much in any one location. As the sediment loads increase and the channel bed aggrades, the river channel would tend to flow in a straight and braided pattern.

Over the long-term, the Elwha River would likely reach a new equilibrium similar to that of the predam river. Aggradation over the long-term would only occur if the river channel were aggrading prior to the construction of Elwha Dam. Geomorphic evidence should be available if such aggradation was occurring, but no such evidence is available.

The HEC-6 model is limited to predicting vertical aggradation of a stationary river channel and flood plain. The model cannot simulate the straightening of the river channel, the lateral movement of the river channel, nor the bank erosion of secondary channels. Although short-term aggradation may increase the 100-year flood stage by more than the amount predicted by the HEC-6 model, the long-term average increase that was predicted by the HEC-6 model (2.5 feet) provides a useful upper limit.

As a check on this upper aggradation limit, the maximum coarse sediment erosion volume (2.6 million yd^3, see table 1) was assumed to deposit evenly over the channel migration zone area (30 million ft^2) downstream of Elwha Dam to the mouth (see figure 2). The average thickness of such aggradation is 2.4 feet. This calculation assumes that none of the coarse sediment eroded from Lake Mills is deposited along the river channel between the two reservoirs, nor makes it to the Strait of Juan de Fuca.

These conservative assumptions provide another check on the upper aggradation limit and agree quite closely with the HEC-6 model results for the long-term condition.

Table 2. HEC-6 Short-term and Long-term Model Results: Differences from Initial Conditions							
Elwha Dam to Strait of Juan de Fuca		100-year flood water surface elevation: difference from initial conditions (ft)			Thalweg Elevations (ft)		
Cross section	River Mile	Initial Elevation (ft)	1971-74 Short-term	1919-70 Long-term	Initial thalweg elevation	Aggradation (+) Degradation (-)	
						Short-term	Long-term
0	0.00	10.1	0.0	0.0	-1.0	3.7	2.8
1	0.38	12.1	2.0	2.0	0.6	0.0	-0.1
2	0.78	19.4	0.5	3.4	9.2	1.4	5.7
4	1.03	24.8	0.4	4.2	13.0	0.9	7.8
5	1.28	31.3	1.0	5.5	21.5	1.7	6.7
6	1.44	34.2	0.4	4.6	21.2	1.5	8.3
7	1.68	39.1	-0.1	3.7	26.6	-0.1	6.0
8	1.92	42.6	0.1	2.1	31.5	-0.1	4.2
9	2.20	47.5	-0.2	3.2	34.9	-0.1	3.4
10	2.50	52.2	0.1	0.8	36.6	-0.1	3.9
11	2.79	56.0	0.5	3.1	42.3	-0.1	3.6
12	2.90	61.6	0.1	1.1	43.0	-0.1	4.6
13	3.10	67.3	0.8	3.1	51.2	3.2	4.6
14	3.24	68.4	1.2	4.9	59.2	1.2	2.2
15	3.29	70.6	1.8	3.9	54.3	6.2	7.5
15A	3.40	75.5	2.0	3.3	54.3	8.5	9.6
16A	3.45	76.2	1.4	3.0	62.5	2.5	3.4
16	3.47	80.4	0.8	1.7	60.6	4.2	4.5
18	3.49	79.8	0.6	1.8	56.9	5.9	5.7
19	3.58	80.8	2.7	3.4	56.2	8.8	6.5
20A	3.68	84.8	-0.1	0.1	72.4	0.0	0.0
20B	3.69	90.2	-0.2	-0.3	69.8	1.4	1.2
20	3.83	90.9	0.0	-0.1	69.8	5.0	2.3
20C	4.04	91.8	1.0	0.8	69.8	10.1	5.2
20D	4.23	92.4	3.1	2.3	75.3	9.2	2.0
20E	4.46	95.0	7.3	5.8	75.3	12.2	2.9
21A	4.84	108.4	12.7	12.6	93.7	-0.1	-0.1
21	4.86	112.3	19.8	19.6	84.8	6.1	7.9
22	4.92	114.9	16.0	16.2	66.8	26.5	25.5
River Miles 0 to 4.04							
Minimum			-0.2	-0.3		-0.1	-0.1
Maximum			2.7	5.5		10.1	9.6
Average			0.7	2.5		2.7	4.6

Elwha River Profile below Elwha Dam
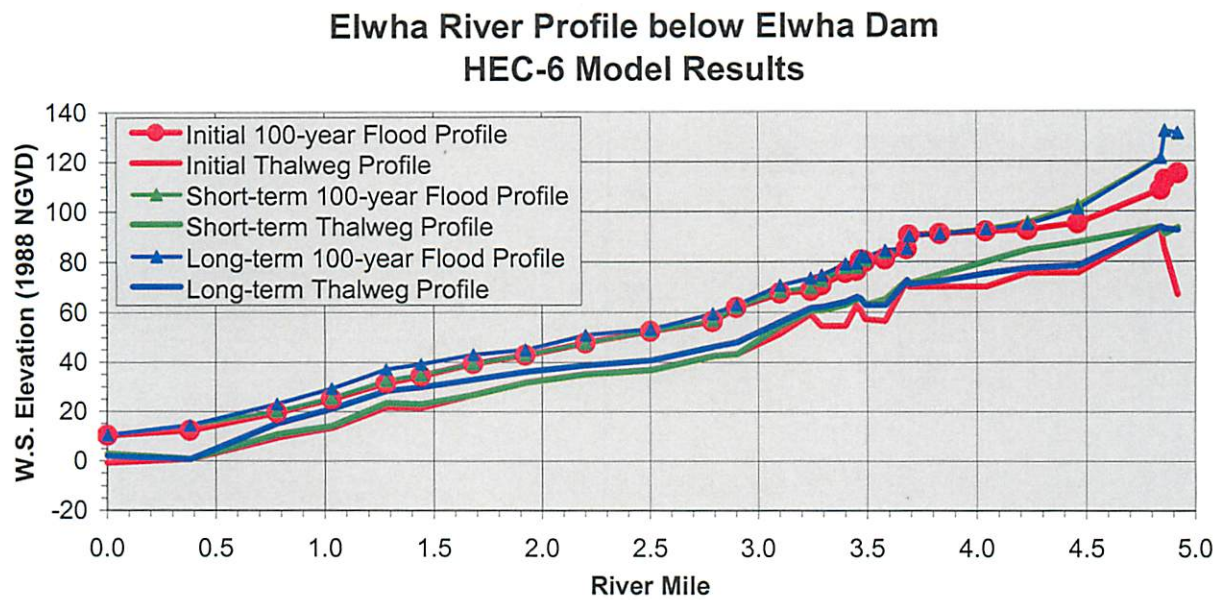## HEC-6 Model Results

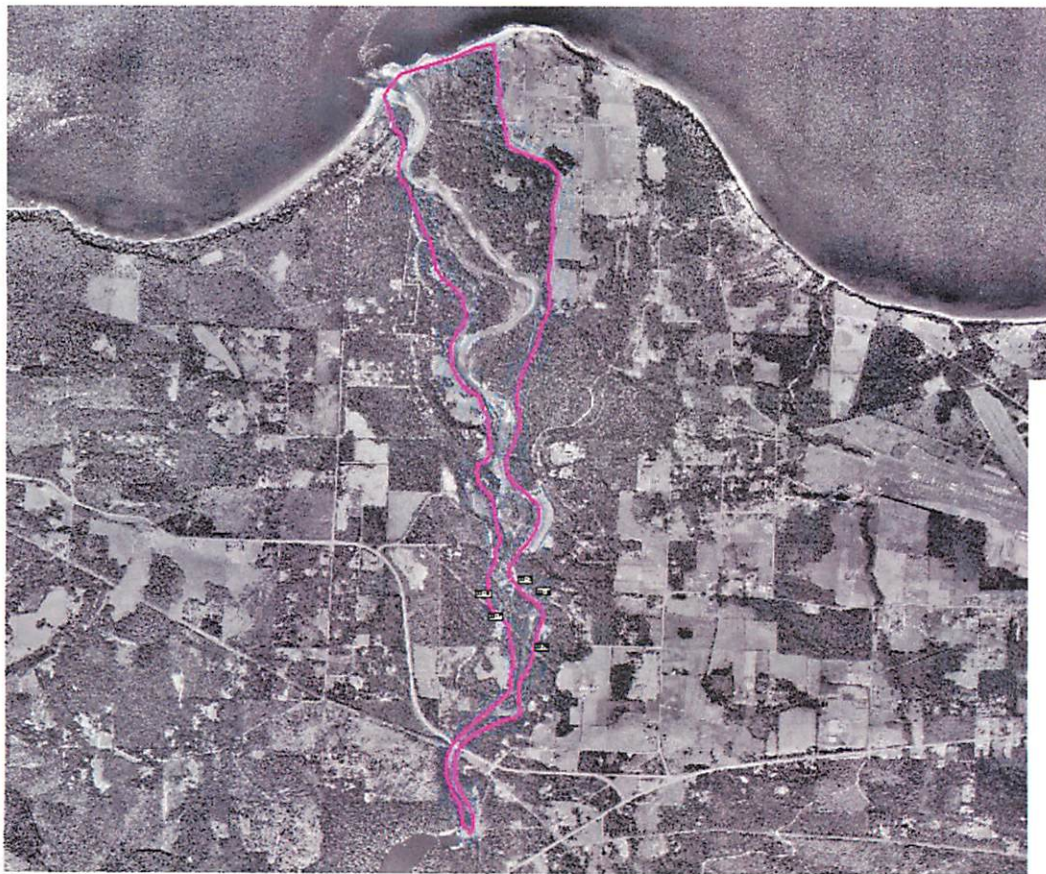Figure 1. Longitudinal River Profile of HEC-6 Model Results.

Figure 2. Channel migration zone boundaries for the Elwha River below Elwha Dam.

New Survey and Hydraulic Model

During the winter and spring of 2001, new surveys were conducted to more precisely define the topography of the river channel and flood plains (Washington North State Plane Coordinates, 1983 North American Datum and 1988 National Geodetic Vertical Datum). During February 2001, a LIDAR survey was conducted to measure the topography of the flood plains and terraces. During April and May of 2001, the river channel bottom was surveyed by raft using a depth sounder and survey-grade GPS equipment. These data sets were combined to provide a digital elevation model of the river channel, flood plains, and terraces. From this combined data set, the U.S. Army Corps of Engineers has constructed 135 cross sections of the Elwha River for use in the HEC-RAS hydraulic model of the river channel and flood plains, downstream from Elwha Dam.

Application of HEC-6 Sediment Model Results to New HEC-RAS Hydraulic Model for River Channel Downstream of Elwha Dam

A longitudinal profile of channel bottom and 100-year water surface elevation was generated from Elwha Dam to the mouth to compare the HEC-6 and HEC-RAS model results (figures 3 and 4). In some locations, the HEC-6 predicted 100-year water surface elevation for the short- and long-term conditions is less than the present water surface elevation predicted by the HEC-RAS model. This is because the new data used in the HEC-RAS model captures more of the hydraulic controls (riffles and rapids) and assumes higher roughness coefficients than the HEC-6 model.

The HEC-6 model results should be used to estimate the average increase in the 100-year flood stage over the short-term period representing dam removal and the first few years following dam removal. The average increase in the 100-year flood stage (0.7 feet for short-term and 2.5 feet for long-term) should be uniformly applied to the final results from the HEC-RAS model. Any attempts to utilize site-specific results from the HEC-6 model results would require more precision than the model is capable of providing. The only other choice would be to conduct a second round of sediment transport modeling, but a model that could simulate more physical processes than HEC-6 would be required. Additional sediment transport modeling could be an expensive and time-consuming task (at least $200,000 and 1-2 years to complete) that may not yield much better information.

Conclusions

The HEC-6 modeling results provide information on potential increases in flood elevations that might occur as a result of riverbed aggradation. Conceptually, short-term aggradation is expected to be greater than long-term permanent aggradation. The HEC-6 model results for the long-term provide an upper limit to the flood stage increase (2.5 feet) caused by short-term aggradation. Therefore, a maximum increase in the existing HEC-RAS water surface profiles of 2.5 feet can be compared with the existing levee elevations to determine if and where the levee height needs to be increased. However, extensive channel migration would have to occur before this maximum amount of aggradation could occur. Therefore, the greatest threat to the levees is most likely from the direct erosion by river velocities when the main river channel migrates adjacent to portions of the levees. The actual amount of riverbed aggradation can be controlled by controlling the rate of dam removal. The monitoring plan has been designed in insure that aggradation would not result in an increase in the 100-year flood stage of more than 2.0 feet.
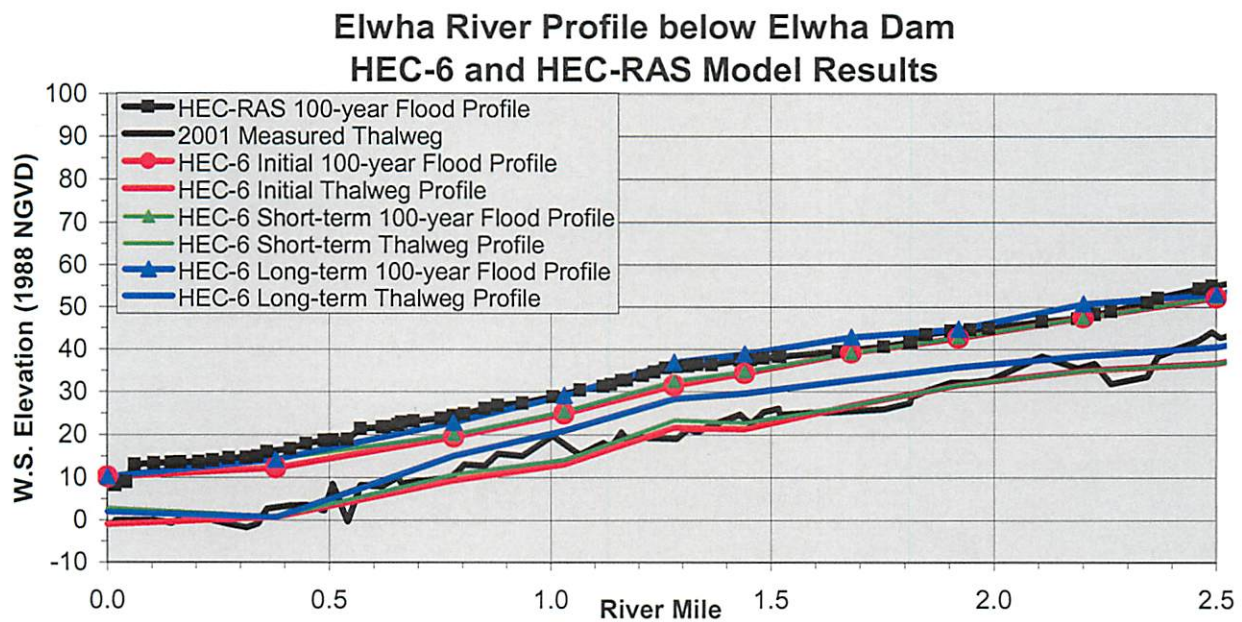
Figure 3. Comparison of HEC-6 and HEC-RAS model results for the reach between river miles 0 and 2.5.
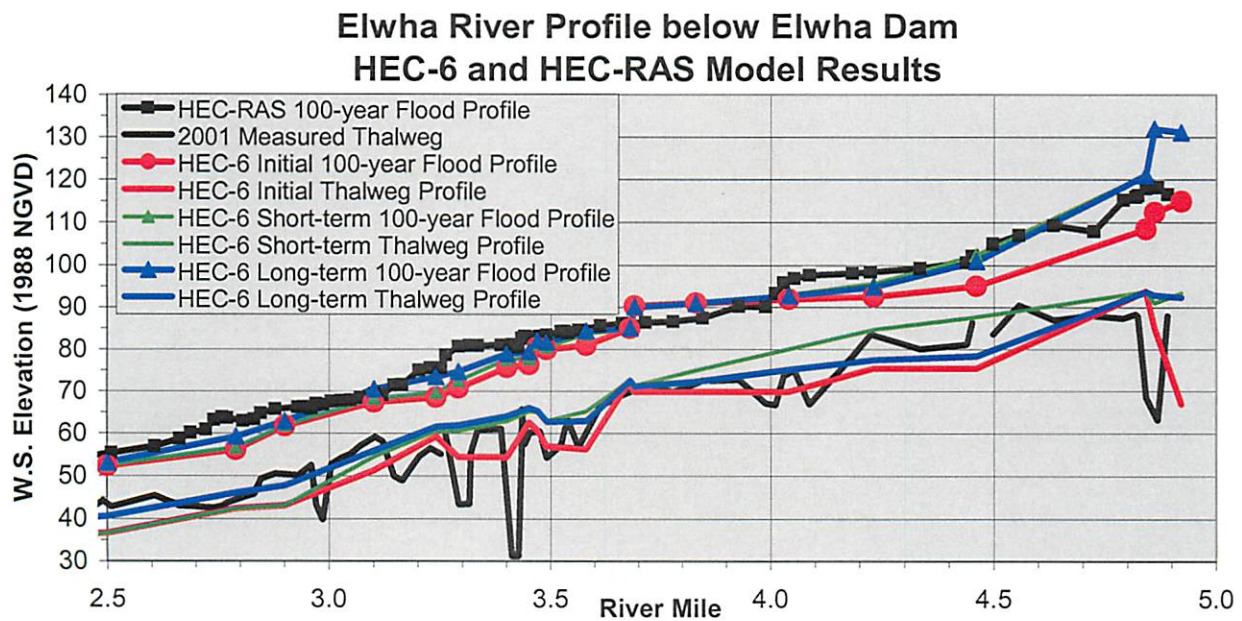
Figure 4. Comparison of HEC-6 and HEC-RAS model results for the reach between river miles 2.5 and 5.

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Appendix B: Average Main-channel Velocities and Sediment Transport Capacities

Average main-channel velocities of the Elwha River between Elwha Dam and the river mouth for discharges of 500, 1,500, and 14,470 ft³/s.

Landmark Description	River Sta (ft)	River Mile	500 ft³/s		1,500 ft³/s		14,470 ft³/s	
			Depth (ft)	Ave Velocity (ft/s)	Depth (ft)	Ave Velocity (ft/s)	Depth (ft)	Ave Velocity (ft/s)
Elwha Dam Powerplant	25,819	4.89	5.0	3.4	6.5	6.3	14.6	15.1
	25,701	4.87	29.9	0.2	31.6	0.4	41.4	2.5
	25,558	4.84	24.4	0.2	26.1	0.5	35.9	3.0
	25,466	4.82	5.0	2.0	6.6	3.4	15.5	8.4
	25,438	4.82	4.5	2.3	5.9	4.5	14.7	9.4
	25,290	4.79	5.4	1.4	6.8	3.1	15.3	9.2
	24,943	4.72	4.8	1.2	6.1	2.7	13.1	11.3
	24,465	4.63	5.8	0.7	7.0	1.7	13.9	7.6
	24,057	4.56	1.8	5.4	2.6	6.7	7.6	13.1
	23,747	4.50	5.4	1.9	6.8	3.7	12.9	11.6
	23,503	4.45	1.7	5.3	2.7	7.0	7.9	14.1
	23,436	4.44	5.0	2.6	7.1	3.9	13.7	10.4
	22,888	4.33	5.6	2.0	7.3	3.3	13.1	8.9
	22,305	4.22	1.2	4.4	1.8	6.2	7.0	9.1
	22,091	4.18	1.6	3.2	3.4	4.1	11.2	8.3
	21,582	4.09	11.8	0.5	14.1	1.1	22.2	4.9
	21,400	4.05	3.0	6.1	5.2	6.8	12.4	11.2
	21,270	4.03	2.6	5.6	4.2	9.1	11.7	13.2
	21,179	4.01	9.3	0.9	11.2	1.9	19.2	6.3
	21,060	3.99	8.9	0.8	10.8	1.8	18.4	7.4
	20,738	3.93	3.2	2.2	4.9	3.4	11.4	8.8
	20,307	3.85	2.2	3.6	3.6	4.4	9.6	8.4
Powerline	19,953	3.78	3.8	1.5	5.4	2.5	11.2	7.0
	19,618	3.72	1.8	2.9	3.4	3.3	9.0	6.1
	19,342	3.66	2.3	4.3	4.3	5.4	10.5	5.9
	19,075	3.61	2.9	5.1	4.9	6.9	12.1	7.0
	18,817	3.56	11.8	0.6	14.0	1.3	21.4	5.9
	18,690	3.54	5.6	1.4	7.7	2.7	14.5	8.3
	18,647	3.53	7.8	0.8	10.0	1.8	16.8	6.9
	18,602	3.52	11.4	0.8	13.5	1.7	20.3	6.8
	18,431	3.49	14.4	0.5	16.5	1.2	23.2	5.4
	18,350	3.48	8.3	1.0	10.3	2.1	17.0	5.9
	18,230	3.45	8.4	0.7	10.5	1.4	16.9	5.9
	18,167	3.44	11.2	0.5	13.3	1.0	19.8	4.7
	18,137	3.44	2.0	7.6	4.3	6.9	11.1	7.5
	18,132	3.43	8.0	2.7	9.5	6.1	18.3	13.8
Existing Diversion Dam	18,095	3.43	32.7	0.3	34.3	0.8	41.0	5.2
	18,020	3.41	32.7	0.1	34.3	0.4	41.1	3.1

Average main-channel velocities of the Elwha River between Elwha Dam and the river mouth for discharges of 500, 1,500, and 14,470 ft³/s.

Landmark Description	River Sta (ft)	River Mile	500 ft³/s Depth (ft)	500 ft³/s Ave Velocity (ft/s)	1,500 ft³/s Depth (ft)	1,500 ft³/s Ave Velocity (ft/s)	14,470 ft³/s Depth (ft)	14,470 ft³/s Ave Velocity (ft/s)
	17,886	3.39	2.7	2.0	4.2	2.8	10.6	6.5
	17,605	3.33	1.9	6.1	3.2	7.4	10.5	6.2
	17,526	3.32	6.1	1.6	7.6	2.5	15.9	4.6
	17,506	3.32	18.2	0.4	19.7	0.9	28.1	3.5
	17,377	3.29	18.2	0.3	19.8	0.7	28.1	3.9
	17,224	3.26	1.9	3.3	3.1	5.4	9.2	13.2
One-Lane Bridge	17,168	3.25	6.4	1.2	7.8	2.6	13.4	11.1
	17,040	3.23	5.0	1.3	6.3	2.8	11.6	9.3
	16,905	3.20	6.9	0.9	8.1	2.2	13.0	8.1
	16,709	3.16	12.5	0.6	13.7	1.6	17.4	9.1
	16,614	3.15	11.5	0.4	12.7	1.0	16.8	5.3
Flow split at top of island	16,476	3.12	3.4	1.5	4.5	2.3	8.1	6.7
	16,383	3.10	1.9	3.8	2.7	5.8	6.3	8.1
	16,213	3.07	1.4	5.0	2.5	5.9	7.4	6.7
	16,093	3.05	1.9	3.8	3.2	6.0	7.7	9.6
	15,980	3.03	2.3	3.0	3.5	4.9	7.7	7.8
	15,868	3.01	2.5	6.4	3.8	6.7	8.6	7.0
	15,764	2.99	14.5	0.8	15.6	2.2	21.0	7.2
	15,689	2.97	11.0	0.9	12.1	2.2	17.4	6.5
	15,631	2.96	1.4	4.8	2.5	5.4	7.8	7.5
Ranney Well	15,539	2.94	1.9	3.4	3.2	5.0	8.0	10.6
	15,471	2.93	2.8	2.5	4.1	3.9	9.1	7.7
	15,203	2.88	1.6	3.2	2.6	4.7	7.9	6.9
EWTP Proposed Solids discharge outfall Location	15,031	2.85	1.2	4.6	1.9	6.1	8.5	7.7
	14,953	2.83	2.9	4.6	4.7	5.0	11.4	8.9
	14,819	2.81	3.3	2.6	5.2	3.7	12.0	7.8
	14,632	2.77	4.2	2.6	5.9	4.2	13.1	5.4
	14,571	2.76	4.5	1.7	6.2	2.8	12.5	8.7
	14,474	2.74	5.0	0.5	6.7	1.1	13.3	4.0
	14,378	2.72	5.1	0.9	6.9	1.8	12.8	7.3
	14,194	2.69	4.9	1.2	6.5	2.1	12.0	7.6
	14,061	2.66	4.8	1.4	6.4	2.5	11.3	8.6
	13,768	2.61	1.9	3.3	3.3	4.5	7.3	9.6
	13,250	2.51	3.0	1.3	4.4	1.7	7.5	5.0
	13,148	2.49	2.9	2.5	4.1	3.2	7.3	4.9
	12,995	2.46	2.6	3.5	3.5	4.4	7.3	5.0
	12,504	2.37	2.2	2.4	3.6	3.0	9.6	6.4
	12,375	2.34	6.7	0.8	8.2	1.9	13.9	6.9
	11,945	2.26	8.4	0.9	9.8	2.0	14.0	8.8
	11,749	2.23	3.4	2.0	4.7	3.2	8.4	8.4
	11,549	2.19	4.5	0.9	5.6	1.9	8.8	6.2
	11,128	2.11	1.3	3.7	1.9	5.1	4.5	7.1
	10,500	1.99	1.9	2.4	3.1	3.3	7.8	6.9

Average main-channel velocities of the Elwha River between Elwha Dam and the river mouth for discharges of 500, 1,500, and 14,470 ft³/s.			500 ft³/s		1,500 ft³/s		14,470 ft³/s	
Landmark Description	River Sta (ft)	River Mile	Depth (ft)	Ave Velocity (ft/s)	Depth (ft)	Ave Velocity (ft/s)	Depth (ft)	Ave Velocity (ft/s)
	10,279	1.95	1.7	1.8	2.8	2.9	7.4	7.0
	10,054	1.90	1.1	3.2	2.1	4.1	7.1	5.0
	9,760	1.85	1.6	2.5	2.7	3.6	8.1	6.9
	9,585	1.82	1.6	5.2	2.3	7.1	8.9	7.0
	9,565	1.81	2.1	2.9	3.6	3.5	10.3	6.4
	9,260	1.75	2.9	1.8	4.5	2.8	11.1	5.3
	8,721	1.65	2.9	2.4	4.3	3.9	10.2	4.9
	8,033	1.52	3.2	1.1	4.2	2.0	9.4	3.8
	8,012	1.52	1.6	2.8	2.5	3.8	7.8	4.5
	7,832	1.48	1.4	2.7	2.5	3.5	8.2	4.3
	7,682	1.45	3.9	1.0	5.0	2.1	10.5	4.4
	7,549	1.43	1.5	2.9	2.4	4.2	7.8	5.5
	7,214	1.37	1.8	2.7	3.4	2.5	9.6	4.6
	7,041	1.33	2.9	1.8	4.8	2.2	11.0	4.1
	6,931	1.31	2.0	1.5	3.9	2.0	10.1	4.1
	6,794	1.29	4.2	0.9	6.1	1.6	12.2	3.2
	6,659	1.26	3.8	1.1	5.7	1.9	11.6	3.8
	6,524	1.24	3.6	0.4	5.3	0.7	11.0	1.1
	6,388	1.21	3.3	1.5	4.7	2.5	10.2	5.1
	6,192	1.17	3.6	1.5	4.9	2.8	10.0	5.8
	6,131	1.16	1.5	3.7	2.6	4.9	7.2	8.6
	6,003	1.14	4.3	0.9	5.6	1.8	10.3	6.0
	5,911	1.12	3.0	1.2	4.2	2.3	8.7	6.1
	5,632	1.07	5.8	0.6	7.0	1.5	10.9	4.9
	5,306	1.00	1.0	3.0	2.0	3.7	5.3	5.0
	4,939	0.94	3.3	1.9	4.9	2.6	8.3	4.3
	4,643	0.88	1.5	4.5	2.8	5.0	6.9	4.3
	4,490	0.85	2.9	2.3	4.4	3.7	8.9	4.5
	4,244	0.80	1.7	4.2	2.9	4.3	7.7	5.4
	4,109	0.78	2.9	1.6	4.9	2.4	10.0	5.3
	3,967	0.75	3.3	2.4	5.2	3.5	10.2	7.3
	3,642	0.69	3.4	2.0	5.1	3.3	10.0	4.7
	3,498	0.66	3.5	2.4	5.1	3.2	9.5	7.5
	3,456	0.65	1.8	3.0	3.4	4.1	7.7	8.4
	3,296	0.62	2.7	3.1	4.2	4.4	8.9	6.2
	3,268	0.62	3.0	1.9	4.6	2.9	9.0	7.1
	3,013	0.57	2.2	2.9	3.5	3.9	8.1	5.8
	2,859	0.54	10.4	1.3	11.6	2.8	16.1	6.0
	2,682	0.51	1.1	4.8	1.9	6.2	5.9	8.0
	2,584	0.49	6.1	1.0	6.6	2.3	11.9	5.1
	2,368	0.45	4.8	0.8	5.1	2.2	9.8	6.4
	2,180	0.41	4.8	0.9	5.0	2.6	9.2	6.4
	1,904	0.36	5.5	0.7	5.6	1.9	8.9	6.7

Average main-channel velocities of the Elwha River between Elwha Dam and the river mouth for discharges of 500, 1,500, and 14,470 ft³/s.

| Landmark Description	River Sta (ft)	River Mile	500 ft³/s		1,500 ft³/s		14,470 ft³/s	
			Depth (ft)	Ave Velocity (ft/s)	Depth (ft)	Ave Velocity (ft/s)	Depth (ft)	Ave Velocity (ft/s)
	1,792	0.34	9.1	0.5	9.2	1.4	12.1	6.9
	1,658	0.31	9.9	0.5	9.9	1.3	12.3	7.3
	1,452	0.27	9.1	0.4	9.2	1.1	11.0	6.3
	1,257	0.24	8.2	0.3	8.2	1.0	9.5	6.5
	1,091	0.21	7.4	0.3	7.4	0.7	8.3	5.4
	870	0.16	8.1	0.2	8.1	0.5	8.7	3.9
	762	0.14	8.9	0.1	8.9	0.4	9.5	3.3
	557	0.11	8.2	0.1	8.2	0.4	8.6	3.3
	325	0.06	8.2	0.2	8.2	0.5	8.2	4.9
River mouth at the Strait of Juan de Fuca	225	0.04	8.2	0.2	8.2	0.5	8.0	5.4
	93	0.02	8.2	0.0	8.2	0.1	8.2	0.5
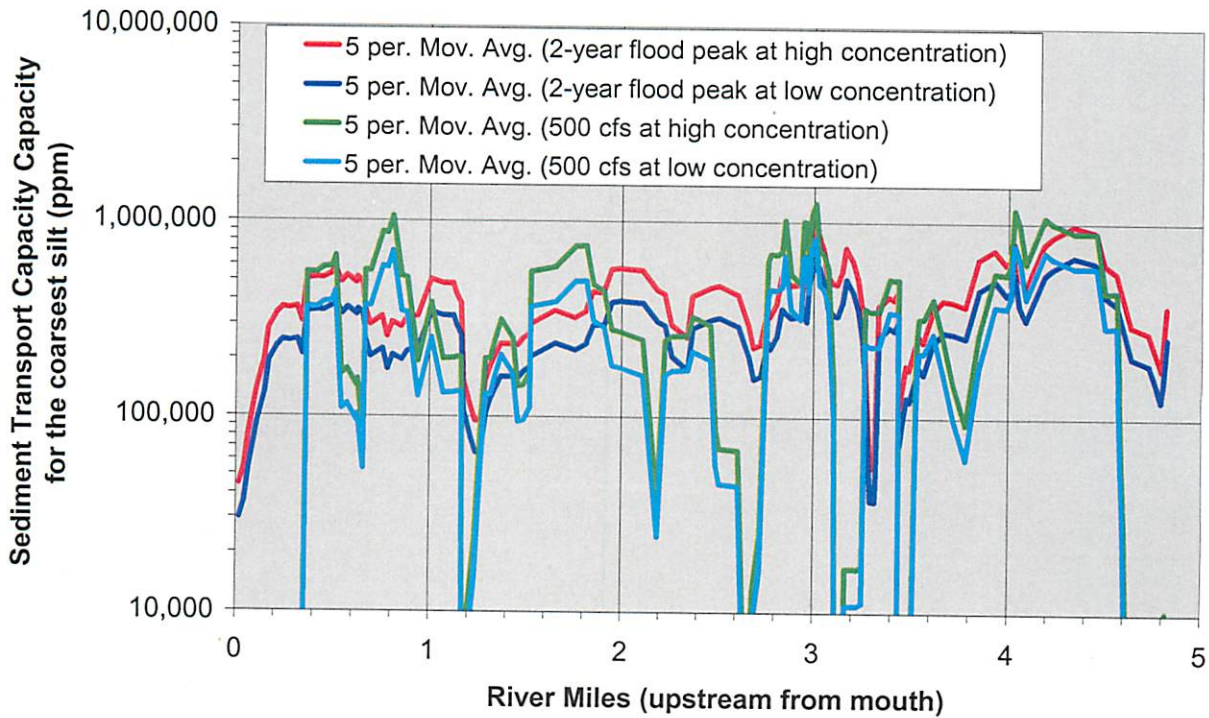
Figure B1. Hydraulic capacity to transport coarse silt particles (0.062 mm) along the Elwha River is shown for river discharges of 500 and 14,470 ft³/s. When sediment concentrations are high (40,000 mg/l), the sediment transport capacity increases due to the increase in density and viscosity of the fluid-sediment mixture.